# APPLICATION OF LEAN MANUFACTURING PRINCIPLES TO DARHT-II INDUCTION CELL REFURBISHMENT *

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## *Abstract*

The induction cells of the Dual Axis Radiographic Hydrotest (DARHT) second axis facility are scheduled to be refurbished with performance and reliability upgrades. The refurbishment process involves extracting each cell from the accelerator hall, performing a complete teardown of the cell, reassembling with new or modified components, fidulizing the magnetic axis, testing and certifying pulse power performance, and reinstalling into the accelerator hall. Each step of the refurbishment process is comprised of many complex steps, necessitating attention to details and following strict assembly protocol to ensure that high quality cell assemblies are attained. All this must be accomplished at an accelerated production rate to meet the commissioning milestones of the DARHT second-axis accelerator. To this end, Los Alamos National Laboratory (LANL) has adopted the principles of Lean Manufacturing and applied them to the cell refurbishment effort. These principles emphasize streamline thinking and methodologies for manufacturing environments that promote the most effective use of resources. After workshops and application of these methodologies, the cell manufacturing facility at LANL has been transformed to support Lean Manufacturing. This paper presents and discusses the processes and facility configuration developed to apply Lean Manufacturing for cell refurbishment.

## I. INTRODUCTION

Electrical and mechanical upgrades to the DARHT-II induction cells design have been developed [1] [2] [3] and will be adopted as part of a major cell refurbishment project at LANL. Figure 1 shows a cross sectional view of the new induction cell design. To implement these upgrades, Lean Manufacturing principles have been adopted. The principles of Lean Manufacturing are found in many areas of mass production, as they are fundamentally applicable to a wide variety of industries, from Navy shipbuilding and repair to automobile mass-production.

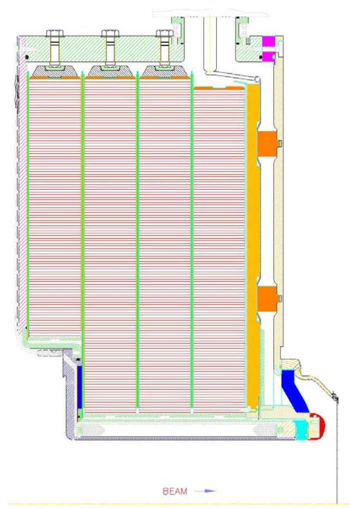


**Figure 1.** Cross sectional view of DARHT-II induction cell with upgrades.

In February 2004, LANL hired a Lean Manufacturing consultant, *Optiprise, Inc.*, to conduct a one week workshop with the cell refurbishment team members. At the conclusion of the workshop, the team had developed a working plan that adopted Lean Manufacturing principles. A high level process map was developed, and a basis for tooling development and configuration of LANL's refurbishment facility was established. The result of the team's efforts to incorporate Lean into the cell refurbishment process is described in the sections that follow.

## II. LEAN PRINCIPLES

The management principles of Lean Manufacturing are extensive and can be found in various publications [4].

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14. ABSTRACT

**The induction cells of the Dual Axis Radiographic Hydrotest (DARHT) second axis facility are scheduled to be refurbished with performance and reliability upgrades. The refurbishment process involves extracting each cell from the accelerator hall, performing a complete teardown of the cell, reassembling with new or modified components, fidulizing the magnetic axis, testing and certifying pulse power performance, and reinstalling into the accelerator hall. Each step of the refurbishment process is comprised of many complex steps, necessitating attention to details and following strict assembly protocol to ensure that high quality cell assemblies are attained. All this must be accomplished at an accelerated production rate to meet the commissioning milestones of the DARHT second-axis accelerator. To this end, Los Alamos National Laboratory (LANL) has adopted the principles of Lean Manufacturing and applied them to the cell refurbishment effort. These principles emphasize streamline thinking and methodologies for manufacturing environments that promote the most effective use of resources. After workshops and application of these methodologies, the cell manufacturing facility at LANL has been transformed to support Lean Manufacturing. This paper presents and discusses the processes and facility configuration developed to apply Lean Manufacturing for cell refurbishment.**

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Lean is defined as “a strategy for achieving significant continuous improvement in performance through the elimination of all waste of resources and time in the total business process” [5]. It evolved from Toyota after World War II as a business strategy due to the limited resources available in Japan, in contrast to the vast resources available to manufacturers in the United States. Its principles apply to nearly all business operations, from administration and product design to hardware production. At its core, Lean Manufacturing is about eliminating waste and non-value added tasks. Examples of waste in manufacturing include overproduction, waiting, unnecessary part movement, overprocessing, excess inventory, unnecessary movement, and defects. As applied to hardware production Lean Manufacturing focuses on eliminating all sources of waste by applying the following strategies: 1) one piece workflow, 2) takt time; and 3) pull systems.

### A. *One piece workflow*

One piece workflow contrasts traditional batch manufacturing methods, where large banks of work-in-process product inventory are produced at each workstation before pushing the inventory to the next production stage. One piece workflow creates a continuous material flow throughout the manufacturing process, eliminates inventory build up, and allows early implementation of corrective measures for problems or defects that surface.

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### *B. Takt Time*

Takt (German word for rhythm) time is the time required to produce a product and is base on customer demand. It is used to establish the time and resources required at each workstation, and levels and coordinates tasks to avoid overproduction or underproduction. This principle applies well to repeatable processes where the steps can be written out to identify the sources of waste. These sources of waste can then be eliminated to improve workflow.

### C. *Pull Systems*

In a one piece workflow system each production step is dependent on material output from the previous step. In a pull system material at a given workstation is processed only when that material is requested by the following production step. This creates “pull” which cascades backwards to the beginning of the manufacturing cycle. Time and resources are effectively used in this fashion by eliminating the production of large inventories of work-in-process that must be stored and tracked.

These principles were applied to develop new tooling systems and to reconfigure the refurbishment facility at LANL for cell refurbishment, which is described in the following section.

## III. REFURBISHMENT FACILITY LAYOUT

Figure 2 shows the reconfigured layout of LANL’s refurbishment facility. The workstations are arranged such that work progresses from left to right, keeping dirty operations on the left from the final assembly work on the right. The final assembly area is also furthest away from the high bay roll up doors to the outdoor environment. The SWAT (Stretched Wire Alignment Technique) stand was not relocated from its original installation. The high voltage testing area is arranged to accommodate multiple cell tests.

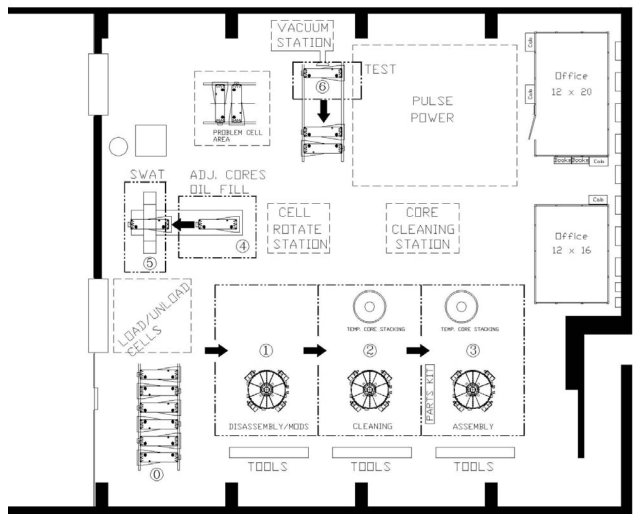


**Figure 2.** Cell refurbishment facility at LANL

The cell refurbishment facility is comprised of seven key work stations: 0) preparation, 1) disassembly and modifications, 3) cleaning and preassembly, 4) final assembly, 5) oil fill, 6) SWAT fiducializing, and 6) high voltage testing. Each workstation includes a set of checklists with specific work instructions and sign-off requirements. In full production, a total of seven cells will be in process at a given time. The output cell production rate, or takt time, is given by the workstation with the longest duration. The following sections provide a general description of the operations at each station.

### A. *Preparation*

Cells transported to the refurbishment facility are initially staged here and are prepared for disassembly. The work is mainly comprised of the following activities:

- Removing power and thermocouple connectors
- Cutting off the bellows with cut-off tool
- Remove cooling manifolds from beam tube
- Remove finger stock and cathode cap
- Remove upper compensation boxes
- Remove support base and transfer to disassembly workstation

### *B. Disassembly and Modifications*

Cells undergo a nearly 100% tear down. Parts are identified for reuse or immediate salvage. The work is mainly comprised of the following activities:

- Remove beam tube, inspect, and send for welding of water-oil interface
- Remove oil plumbing from cell
- Remove anode-cathode insulator, inspect, package and send out for modifications
- Remove high voltage plate, inspect, package and send out for modifications
- Remove the compensation cans
- Remove and store cores for cleaning
- Modify housing and downstream endplate with design upgrades

### *C. Cleaning and Preassembly*

The cell components are then transferred to this workstation for detailed cleaning and inspections. Among all cell components, particular attention is paid to the following areas:

- Tapped holes for the core positioning screws are chased through and flushed thoroughly to remove legacy Teflon grease contamination
- O-ring grooves inspected and repaired if required
- Nitrile or Buna-N O-rings are replaced with Viton O-rings
- Housing is leak checked

Cores are cleaned individually as they are needed by the assembly station to minimize the amount of handling steps required for each core. Both the top and bottom surfaces of a core are cleaned on a special core cleaning stand to allow a worker safe access to both surfaces for cleaning. Cores that have experienced arc damage will have the localized damaged cleaned by manual agitation with a small brass wire "toothbrush" and soft cloth wipe until evidence of arc damage is gone.

### *D. Final Assembly*

The final mechanical assembly is performed with great attention to detail and cleanliness. Cores that have been cleaned are immediately inserted into the cell housing to minimize exposure to the ambient environment. Alignment and guide fixtures are pre-installed to provide repeatable core position with an initial vertical offset of 0.155" to compensate for core sagging when the cell is reoriented to the upright position. A leak check of the vacuum region is performed before transferring it to the next workstation for oil filling.

### *E. Oil Fill*

One of the important steps in the cell refurbishment process is filling the cell with insulating oil after assembly. Even with care during the assembly process, the cores may still contain very small traces of debris along the surface of the windings. This debris may land on a surface that is subjected to a high electric field and may lead to tracking when the cell is pulsed. For similar reasons, it is important that air and moisture are not introduced into the oil volume during oil filling.

To address these points, this workstation incorporates a meticulous procedure for transferring oil into the cell. This procedure includes an oil purification process followed by vacuum backfilling to ensure low air and water content. Small debris removal is promoted through multiple fill and drain cycles.

### *F. SWAT Fiducializing*

The cell is rolled into the SWAT station for determining the magnetic axis of the cell and transferring the magnetic axis to a fiducial plate above the cell.

The SWAT fiducializing involves pulsing a stretched wire that is initially mechanically aligned to the center of the beam tube. With the cell solenoid powered on, the stretched wire response to the pulsing determines the magnetic center. The cell is readjusted accordingly to match the magnetic center that is calculated. An alignment reference plate on top of the cell is then permanently secured to the top of the cell with epoxy. The location of this alignment plate corresponds to the alignment monuments in the DARHT-2 accelerator hall.

### *G. High Voltage Testing*

Completed cells will undergo an acceptance test prior to installation at DARHT. This test is comprised of a predetermined startup sequence followed by a specified number of pulses. Any cell that passes this sequence without failure is accepted as ready for installation and retesting at DARHT. Successful cells are staged and prepared for transportation to DARHT.

## IV. QUALITY ASSURANCE

A benefit of the one piece workflow process is that it builds-in quality at all stages of the production process. Each workstation has an inspection role and works to correct problems before passing them on to the next step. Problems can be detected much more quickly in this fashion and can be diagnosed and corrected immediately. The quality control program established for cell refurbishment focuses on building in quality at the floor level. One method that accomplishes this is by streamlining all workflow and process steps; e.g. as in the development of tooling systems to reduce part handling, or reducing the number of times the cell is oil-filled and drained. Another method is by the use of checklist procedures that are written succinctly. These procedures comprise the contents of a cell refurbishment manual, which is the central document binder that accompanies each cell. This manual includes relevant fabrication information such as checklists, subcomponent processing instructions, nonconformance and corrective action measures, and technical and quality hold points. A dedicated quality assurance specialist is integrated with the cell refurbishment team to create a quality presence during cell refurbishment.

## V. SUMMARY

A new DARHT-II cell design has been developed with electrical and mechanical upgrades. These upgrades will be implemented by a refurbishment production line that follows the principles of Lean Manufacturing. New tooling and a new refurbishment facility configuration were developed as a result. The new cell refurbishment facility is comprised of seven workstations, each performing a unique set of tasks on a cell. A quality assurance program integrated with the floor level operations will ensure all induction cells are assembled with high quality standards.

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